October 1999

Science & Technology REVIEW

U.S. Department of Energy's
Lawrence Livermore
National Laboratory

LIVERMORE TAKES SIX R&D 100 HONORS

Optical Modulator and Switch

Gamma Watermark

High-Power Green Lasers

Accelerator Power Source

Precision Deposition

PEREGRINE™

About the Cover

Powerful pulses of green light are generated by the diode-pumped solid-state laser system shown on the cover, one of six Lawrence Livermore winners in this year's *R&D Magazine* competition for the 100 best research and development projects. In the picture, a technician has pulled out the laser to align it so that the optical fibers will deliver the multihundreds of watts of green light to a user facility. This laser was one of four operating around the clock; all together, they accumulated greater than 40,000 device hours of operation. The articles beginning on p. 4 describe this and the other R&D 100 winners from Livermore.

Cover design: Ray Marazzi

About the Review

Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy. At Livermore, we focus science and technology on assuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published 10 times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

Please address any correspondence (including name and address changes) to *S&TR*, Mail Stop L-664, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94551, or telephone (925) 422-8961. Our electronic mail address is str-mail@llnl.gov. *S&TR* is available on the World Wide Web at www.llnl.gov/str/.

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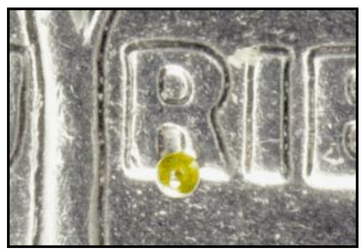

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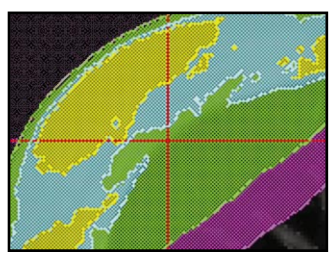

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Lab inventor puts new twist on ball bearings

Livermore physicist and inventor Dick Post has an alternative to the ball bearing, a part that is found in nearly every moving machine. Post's design, called the passive magnetic bearing, will eliminate the friction that is created when metal bearings roll against each other and will let them last longer, with fewer breakdowns. Such ball bearings would be particularly useful for long-running, low-maintenance machines located in remote or not easily accessible places such as space.

Magnetic bearings have been around for some 15 years. In these bearings, two powerful, repelling magnets are attached to the two bearing parts—one part turning and the other remaining in place—to prevent them from touching and creating friction. But the magnets need help to stay centered to each other. In existing magnetic bearings (called active magnetic bearings), a series of electronic sensors pushes the turning magnet back in place when it starts to slip to one side or the other of the in-place magnet.

Post's passive device uses no electronics and instead is based on a fundamental rule of physics: when a wire moves through a magnetic field, it creates an electrical current, and conversely, an electrical current moving through a wire creates a magnetic field around the wire. Post's device uses a magnet on the unmoving part of the bearing and a bundle of wires on the turning part. In the vicinity of the magnet, the turning motion creates an electrical current, which in turns creates a magnetic field. The induced magnetic field both repels the magnet on the static bearing part and pushes the wire bundle toward the center to keep the magnet arrangement equalized.

Post is cooperating with Trinity Flywheel Power, a company in Livermore, to translate his design into practice. Trinity's machines store energy; the new bearing would make it possible for the machines to run continuously for some 20 years, virtually maintenance-free.

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Sensing perfection in paper

A system for monitoring moisture in paper has been developed by two Lawrence Livermore engineers to help detect moisture irregularities during the manufacturing process and correct them immediately, before large quantities of off-quality paper are produced.

The system devised by Jose E. Hernandez and Jackson Koo uses two linescan cameras mounted directly on a paper machine to continuously monitor the full width of a sheet of paper as it is being made. The camera technology is new and is based on an indium-gallium-arsenide linear array that measures near-infrared light. Hernandez and Koo have selected specific wavelengths sensitive to the higher moisture levels of paper early in the manufacturing process, so monitoring can begin earlier. Their initial results are promising and are catching the attention of paper manufacturers.

Hernandez and Koo started their project in 1996 as part of the Industries of the Future program sponsored by the DOE Office of Industrial Technology. The program creates partnerships between industry, government, and laboratories to identify technologies that can improve the energy efficiencies of nine energy- and waste-intensive industries.

The moisture monitoring system will help paper manufacturers reduce energy by not overdrying paper and minimize waste generation by detecting and correcting moisture problems before large quantities of defective paper are produced.

Hernandez and Koo built a prototype benchtop system in 1997, and last year they teamed up with ABB Industrial Systems in Ohio to test their new system on moving paper. "We wanted to compare our measurements with that of a commercial scanning unit," said Hernandez. "The folks at ABB were very impressed, considering that our sensor technology is substantially different from theirs," he added. This fall, Hernandez and Koo will test two new cameras and conduct more controlled experiments to quantify how well their system can measure moisture in different types of paper.

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Many asteroids are rubble piles

Mark Hammergren, a planetary scientist at Lawrence Livermore, has studied nearly 850 asteroid observations by astronomers and come to this conclusion: elongated or stretched asteroids are apparently weaker than spherical ones. They are never seen to be rotating faster than once every 4 hours, while the more spherical asteroids can rotate as fast as once every 2.3 hours. Hammergren said that this observation supports the theory that most asteroids are not solid chunks of rock tightly bound together but rather are loose aggregates of materials called "rubble piles." The elongated asteroids, with weaker gravity at their ends, cannot rotate faster or their piles of rubble would break up.

Hammergren theorizes that rubble-pile asteroids are governed by the same processes that lend stability to piles of sand on Earth. The rubble piles have the ability to support large surface features on asteroids, just as loose sand and weak dirt can support mountains on Earth. Hammergren also thinks that changes in a rubble-pile asteroid's shape would happen cataclysmically as a series of massive landslides and that if such landslides were to occur on the surfaces of rapidly rotating asteroids, fragments of the asteroid's surfaces may be thrown off into space to form asteroid moons.

Hammergren presented his findings at the centennial meeting of the American Astronomical Society in Chicago earlier this year.

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This Year's R&D 100 Honors

IN this issue, *S&TR* salutes the men and women at Lawrence Livermore who have been recognized by *R&D Magazine* for developing 6 of the 100 most technologically significant new products and processes of the past year. The magazine, a publication for scientists and engineers, has been holding the R&D 100 Awards competition since 1963 to recognize important technological advancements that promise to improve people's lives.

The most recent competition saw outstanding entries from many of the most prestigious companies, research organizations, and universities in the world. All entries were judged by the magazine's editors and by some 70 outside experts chosen from among professional consultants, university faculty, and industrial researchers who are experts in the areas they judged.

The Laboratory's awards for 1999 are elegant solutions to complex technical problems that span an unusually broad range of fields: laser machining, communications, accelerators, chip manufacturing, cancer therapy, and law enforcement. In-depth descriptions of the winning technologies begin on p. 4.

Our achievement is part of a remarkable performance by Department of Energy research facilities that together won 40 of this year's awards. Of that total, sixteen were won by the three DOE national security laboratories—Livermore, Los Alamos, and Sandia. Over the past three years, Lawrence Livermore scientists, engineers, and technicians have brought home 20 R&D 100 awards. Since 1978, our researchers have captured 81 such awards.

As in past years, most of Livermore's awards are spinoffs of national security–related technology or research. For example, Labratory experts applied their experience in nuclear science, radiation transport, and Monte Carlo mathematical techniques used in weapons research to develop PEREGRINE, a system for more accurate radiation dose calculations for cancer patients. In a similar manner, the Livermore team that developed the Optical Modulator–Switch, an important advance for the communications industry, had initially conceived the device for use on nuclear weapons.

I am pleased that this year's winners come from four Livermore directorates—Laser Programs, Physics, Defense and Nuclear Technologies, and Engineering. I am also pleased that our teams collaborated with colleagues from outside the Laboratory, including Bechtel Nevada, Limited Liability Corporation for Extreme Ultraviolet Lithography, U.S. Enrichment Corporation, AlliedSignal Federal Manufacturing & Technology, and the University of Maryland.

The award-winning technologies are as follows:

- Optical Modulator–Switch, which provides simple and inexpensive solutions to the high cost of modulating data onto a laser beam and switching signals from one data channel to another.
- Gamma Watermarking, a revolutionary method of identifying material objects, from dinosaur bones to art, using minuscule amounts of gamma-emitting radioisotopes to achieve legal incontrovertibility equivalent to DNA fingerprinting.
- Diode-Pumped Solid-State Green Laser for Industrial Material Processing, a new laser technology that provides a cost-effective, high-powered replacement to lamp-pumped, solid-state lasers for a host of tasks in laser isotope separation and precision laser machining.
- Atomic Precision Multilayer Deposition System, a faster, cheaper, and more precise method for depositing multilayer thin films to specific atomic thicknesses over large flat or curved surfaces, an important development for extreme ultraviolet lithography.
- Solid-State Power Source for Advanced Accelerators and Industrial Applications, a technology that greatly increases the strength of electron beams that are used to produce bursts of x rays for examining the effects of aging on the nation's nuclear weapons stockpile.
- PEREGRINE™, a hardware and software system that determines accurate, three-dimensional dose calculations for radiation therapy patients by using fundamental physics principles.

My congratulations to all of the 52 Lawrence Livermore researchers who worked on the award-winning projects. Scientific and technological creativity is clearly flourishing at Lawrence Livermore and throughout the DOE family.

■ Jeff Wadsworth is Deputy Director for Science and Technology.

The Optical Modulator and Switch: Light on the Move

Ted Wieskamp (left) and Bob Stoddard conceptualized the Optical Modulator–Switch and collaborated with teams from AlliedSignal and the University of Maryland at College Park to develop the device.

WHETHER it's the Internet or telephone lines, most communication systems these days rely at least partly on fiber optics to carry information in the form of light signals. The most daunting fiber-optic problems facing the communications industry are the high costs of modulating data signals onto a laser beam and switching signals from one channel to another. The recently developed Optical Modulator–Switch (OMS) provides a simple, inexpensive solution to both problems in a single, small package.

The OMS was initially conceived by Bob Stoddard and Ted Wieskamp of Lawrence Livermore's Engineering Directorate as a possible optical strong link that could be used in weapon systems. AlliedSignal Federal Manufacturing & Technology in Kansas City designed the switch, while the University of Maryland at College Park provided integrated circuit design and development for the R&D 100 Award–winning system.

"At the Lab, we wanted a switch that could be coded," Wieskamp explains. "We got that and also signal amplification in the bargain. The final design of this device provided a significant amount of gain when the switch was on. This made it really useful for communications applications."

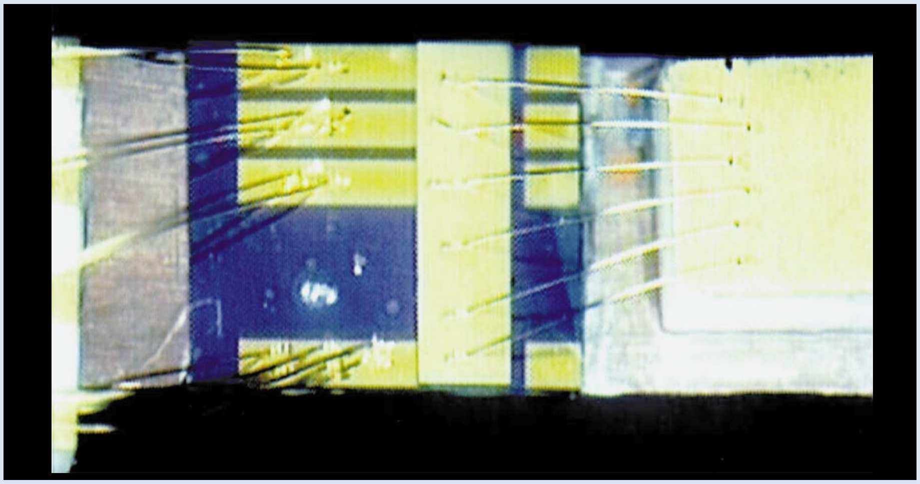
The principal application of the OMS is as a modulator or switch in optical communication systems. However, Wieskamp points out, it could also be used as a control device for laser systems, as a security device for data communication systems, as a lock to protect valuable property, and as a switchable amplifier for small laser signals.

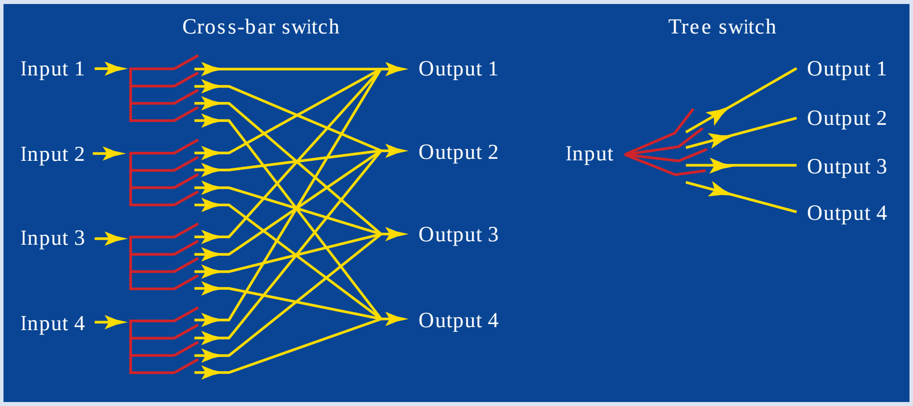
OMS as a Modulator

In fiber-optic communications, information can be carried by a light wave of varying amplitude (changing brightness). The amplitude is varied by modulating the single-wavelength light coming from a laser source. The OMS varies the brightness of a low-level laser light source by switching it on and off at nanosecond rates. Then its built-in amplifier boosts the varying signal to levels suitable for transmission over long optical communication links.

As Wieskamp explains it, commercially available modulators do not amplify the signal. This means that a separate amplifier—

The optical modulator–switch. Fiber-optic input lines come in from the left and attach to the switches on the series of horizontal bars. The built-in amplifier lies under the vertical bar in the center; output lines exit to the right. The entire device fits on the end of a pencil eraser.





In a cross-bar switch (left), any of the inputs may be amplified and connected to any of the outputs. This type of switching is commonly used in optical communication. In a tree connection (right), a single input may be connected to any combination of outputs. The more outputs used, the more important it is to amplify the signal. Here, each output will have about one-quarter of the original input power. If ten outputs are needed—a common configuration for the communications industry—each output signal will approach one-tenth of the original.

which can cost thousands of dollars—must be added to the communication chain after the modulating device.

The OMS device, contained on a chip as big as a medium-size integrated circuit, derives its built-in amplification from the interaction of input signals with semiconductor material. Inside the device, photons from the input signal travel through a waveguide with an applied electric field. This electric field has been exciting atoms in the device's semiconductor material and increasing their energy. When the photons pass through the semiconductor, they cause the semiconductor atoms to give up energy and become photons just like them—of exactly the same wavelength, traveling in the same direction. This increase in the number of photons thus amplifies the signal.

OMS as a Switch

When used as a switch, the OMS can receive signals in different configurations and switch them out in any combination of outputs. The figure above shows its use in both cross-bar and tree switching of optical signals. In switching the optical signals—again, an on-and-off action—the OMS is a thousand times faster than current optical switches.

With many signal outputs, amplification becomes particularly critical. An optical signal can lose half of its input power every time it is sent through a switch or any type of connector; it loses an equal amount traveling through 4 kilometers of fiber. For a signal going across the country, from, say, San Francisco to Washington, DC, this adds up to significant power losses. To counteract these losses, such signals must be amplified or boosted as they are switched and relayed over complex routes or long distances.

Cheaper, Smaller, Simpler, Faster

The OMS has no direct competitors, because no other device has its combined modulation and switching capabilities. Even with its superior capabilities, the OMS still wins hands down in terms of cost, size, simplicity, and speed when compared with commercially available systems. For instance, mechanical and heat-operated switches cost in the neighborhood of $500, while nonlinear optical switches cost about $5,500. The OMS costs less than $50.

As for size, mechanically operated or nonlinear optical switches are about the length of this line of text and are about as wide as a four- or five-line paragraph on this page. Other switches, including heat-operated switches, are far larger. The OMS is 1 by 4 millimeters, barely large enough to cover the end of a pencil eraser.

Commercially available switches tend to have complex designs that depend on expensive technologies. Heat-operated switches depend on expensive polymer waveguide technology. Mechanically operated switches use devices such as moving fiber collimators, which are both expensive and slow. The nonlinear optical switch requires careful alignment of precision-machined crystals, a time-consuming and expensive process. In addition, the nonlinear switch requires external electronics and is highly sensitive to changes in temperatures. The OMS uses conventional integrated circuit technology, making it simple and inexpensive to manufacture. Its built-in amplification further reduces complexity and increases reliability.

The OMS also saves space. "Space is expensive," says Wieskamp. "If you can shrink switching and routing components so equipment fits into a one-story building instead of a four-story building, then you save a lot of money.

"The OMS is a true state-of-the-art development in modem optics," concludes Wieskamp. "No other device is currently available that both modulates and amplifies an optical communications signal. It's a real breakthrough in modulation and switching."

—Ann Parker

Key Words: amplitude modulation, fiber-optic communications, Optical Modulator–Switch (OMS), signal amplification.

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From Dinosaur Bones to Software, Gamma Rays Protect Property

The Gamma Watermark team members are, from left to right, Ronald Lougheed, Tzu-Fang Wang, Muriel Ishikawa, Lowell Wood, Winifred Parker, and Kenton Moody.

LAW enforcement officials have long searched for a way to solve a frequently vexing problem: determining the rightful ownership of everything from paintings to dinosaur bones to computer software. The problem has worsened in the past few years as increasingly sophisticated counterfeiters have flooded markets with illicit copies of a vast range of goods, and thefts of precious items have skyrocketed.

A Livermore research team has come to the aid of law enforcement agencies with an ingenious solution that uses a combination of radioisotopes, gamma-ray spectroscopy, and computer-driven inkjet printers. During the past year, the team developed a novel technology that produces watermarks (unique identifiers) that establish indisputable links between owners and their property.

The team's Gamma Watermark process puts a unique, date-stamped tag of nearly microscopic size on or within an object and does so easily, inexpensively, and safely. The essentially invisible watermark, containing a precisely metered mixture of radioisotopes, can be sensed and read out for decades thereafter with an appropriate detector. Use of the Gamma Watermark establishes ownership irrefutably and is analogous to DNA fingerprinting.

The new technology promises to be as revolutionary a method of identification and authentication as the digital watermark has become to digitized visual and audio data. The process is applicable to a vast range of material objects, from artwork and CD-ROMs to paper items such as contracts and deeds. In contrast to other forms of watermarking (digital, paper, and embedded silicon chips), the process should enjoy far wider applicability because of its low cost, tiny size, ease of use, and safety.

Signatures with Radioisotopes

Gamma watermarking produces a unique digital signature using minuscule quantities of combinations of rare and long-lived isotopes that emit extremely low levels of gamma radiation. One way that Gamma Watermarks may be produced is by selectively adding these radioisotopes to the different inks of a computer inkjet printer.

Dozens of radioisotopes, which are not naturally present in the environment to any significant extent, are suitable for composing a Gamma Watermark. Because each radioisotope emits gamma rays of a different wavelength, combining different radioisotopes in different ratios produces a gamma-ray signature equivalent to an electronic bar code.

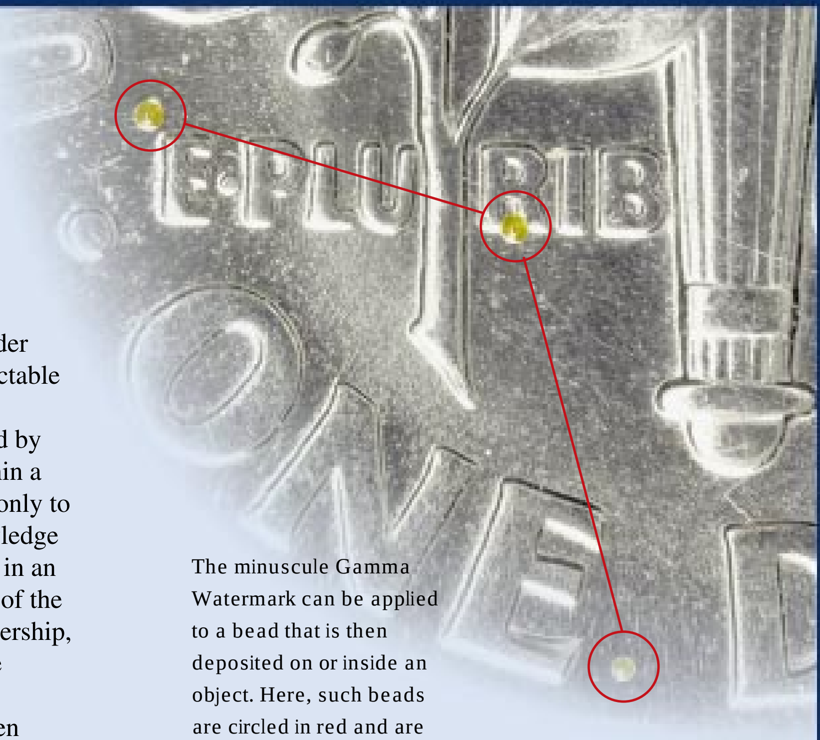
As a result of the exquisite sensitivity and energy resolution of modern commercial gamma-ray detectors, which can record a single nuclear decay with high efficiency and precision, the amount of activity required to continuously express a unique digital signature may be as small as a tenth of a nanocurie (billionth of a curie). Correspondingly, the total mass of the watermark may be well under 1 microgram (millionth of a gram).

In addition to the signature, the watermark contains a built-in "clock" that provides a date stamp of its creation. This clock is initially set to a 1:1 ratio of the intensities of two radioisotopes with different half-lives. At any later time, the observed ratio of these two isotope intensities indicates how much time has elapsed since the watermark's creation. The team anticipates that the usual life span of a Gamma Watermark will be a few decades. However, a mixture of radioisotopes could be selected that would last for centuries.

A typical Gamma Watermark measures about 0.01 centimeter in diameter, smaller than the period at the end of this sentence. The watermark can be applied directly to a piece of paper (a stock certificate, for example) or to a practically microscopic solid bead or token for placing on or within virtually any object.

Watermark Can Be Buried

For added security in objects such as museum pieces, the watermark can be placed inside a tiny hole drilled into a piece



The minuscule Gamma Watermark can be applied to a bead that is then deposited on or inside an object. Here, such beads are circled in red and are shown on a dime for scale.

and then sealed, rendering it virtually invisible, even under close examination. (The gamma rays would still be detectable from buried locations up to a few centimeters in depth.)

The watermark may be detected and its signature read by placing a sensitive gamma-ray detector precisely to within a few millimeters over its location, which may be known only to the object's owner. Indeed, the legitimate owner's knowledge of a Gamma Watermark's secret physical location on or in an object permits its speedy recovery if stolen. Knowledge of the watermark's location also provides confirmation of ownership, which does not depend on the owner's knowledge of the watermark's content.

Rapid detection of the Gamma Watermark occurs even though its total radioactivity is one ten-thousandth of the naturally occurring radioactivity in a human body or a household smoke detector, or a quarter of that of a single banana. Although the watermark's overall intensity is very low, its spectral brightness at certain narrowly defined gamma-ray wavelengths is high and is easily detected.

The extremely low level of gamma-ray emissions, hidden in the ubiquitous natural background radiation, assures complete safety for personnel and helps to further conceal the watermark. Co-inventor Lowell Wood compares detecting the watermark's emissions of less-than-background intensity to someone locating a rare orchid growing deep within a vast rain forest. Without knowing the exact location of an object, someone sweeping for it with a detector might require days to locate its watermark. What's more, the location cannot be discovered through typical examination means such as x rays or sound waves.

New Weapon for Museums

One of the technology's first uses may be to provide an unprecedented level of theft and counterfeiting protection to museums and collections, both public and private. The U.S. Bureau of Land Management (BLM) is interested in the system as a way of protecting fossils and other artifacts located on public lands. A tagging system based on the Gamma Watermark would aid the BLM and law enforcement agents in recovering fossils illegally obtained from public lands, as well as provide evidence for subsequent prosecution. The system would also allow paleontologists and archaeologists to tag specimens while still in the field. Companies that produce computer software are also interested in the technology as a means of foiling rampant counterfeiters and of permanently branding their products by providing counterfeit-resistant (and hidden) certificates of authenticity.

Although the product price will be determined by companies licensed to use the novel technology, the mass production unit cost of some forms of the Gamma Watermark is estimated to be a small fraction of one dollar. The extraordinarily low price is due to the extremely small quantity of radioisotope needed for each watermark. A small vial of radioisotope, for example, might be sufficient to generate 10 million watermarks. (The cost of reading a Gamma Watermark, of course, is expected to entail much higher costs because of the detection equipment and trained personnel required.)

Team members envision that the technology will gradually infiltrate households. In a few years, someone might purchase a Gamma Watermark kit at an office supply store and use it to uniquely identify a valuable personal possession. From museums to stores to living rooms, the new technology is sure to make an indelible mark on countless items—and help people in all walks of life protect their property.

—Arnie Heller

Key Words: DNA fingerprinting, digital watermark, gamma rays, Gamma Watermark.

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High-Power Green Lasers Open up Precision Machining

The Diode-Pumped Solid-State Green Laser (DPSSGL) development team includes, from left to right, Jim Chang, Christopher Ebbers, Isaac Bass, and Curt Cochran. Not pictured is Ernest Dragon.

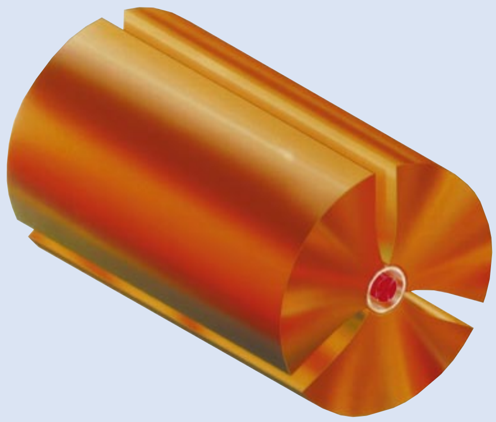
THE power of green light is requisite to the world of precision laser machining. During the past decade, pulses of green light have come from copper-vapor lasers and lamp-pumped solid-state green lasers, but ever-growing demand for higher performance and reliability have pushed these laser systems beyond their capacity. Now, an R&D 100 Award–winning system based on a Diode-Pumped Solid-State Green Laser (DPSSGL) looks to be a natural contender for meeting these demands. In addition to its use for precision machining, the high-power pulsed green laser can be used to pump ultrashort-pulse lasers, create laser displays, and treat disfiguring skin conditions such as port-wine stains.

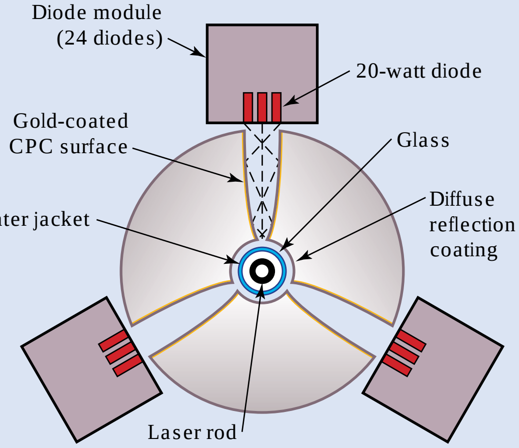
The DPSSGL—developed by physicist Jim Chang and others from Lawrence Livermore's Laser Programs Directorate and from the United States Enrichment Corporation—provides more than 300 watts of pulsed green output at 10 to 20 kilohertz. This is a world record for green-light generation and far outshines the capabilities of commercial copper-vapor lasers, which provide up to about 120 watts, and lamp-pumped solid-state green lasers, which provide about 50 to 100 watts.

The DPSSGL is also much more reliable than current systems. For instance, a lamp-pumped system or a copper-laser system used in an industrial setting lasts only about a month, at which time the lamps must be replaced or the copper reloaded. This maintenance requirement not only increases the operational cost of these systems but also prevents them from being used in applications that require long-duration continuous operation (such as in machining for the automotive industry). Because of its innovative design, the new laser can be run around the clock for more than one year without major maintenance. Moreover, its electrical efficiency ranges from 7 to 8 percent, in contrast to electrical efficiencies hovering around 1 percent for both the lamp-pumped green laser and copper-vapor laser.

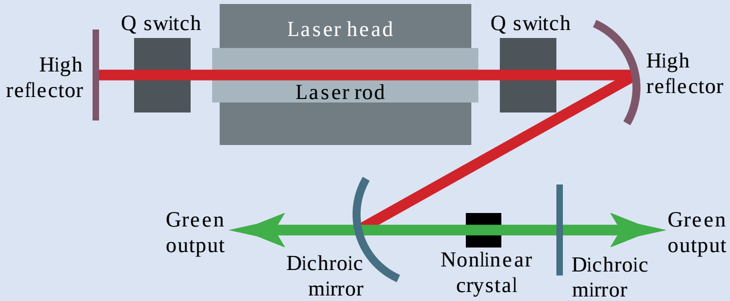
Innovative Design Halves Costs

Although diode-pumped green lasers gradually have been replacing many lamp systems for low-power applications such as laser marking and titanium–sapphire laser pumping, their use in high-power applications has been hindered by their complexity and cost, because of the large number of diodes they use. Chang and his team developed an innovative design that greatly simplifies laser construction and cuts the system's cost by 30 to 50 percent, making it a viable replacement for high-power lamp-pumped systems.





Schematic of the diode-pumped solid-state green laser (DPSSGL) pumping concept. Light from a diode is compressed by the compound parabolic concentrator (CPC) through a small slit into the chamber surrounding the laser rod. There, the rod absorbs the diode light and converts it into infrared laser light.



Above, a schematic of the optical system shows how infrared light emerging from the compound parabolic concentrator (CPC) laser head is converted into pulsed green light. At right, a technician is shown working with the laser.

The DPSSGL uses light from high-power laser diodes to optically excite a solid-state laser rod. The radiation from the diodes normally diverges rapidly; in this case, the light is concentrated by two parabolic surfaces, called a compound parabolic concentrator (CPC). The CPC compresses the diode light through a small slit into a chamber surrounding the laser rod. The light is trapped in the chamber, where the rod can then efficiently absorb it.

Chang notes that the CPC's efficiency in compressing the light is better by a factor of 3 to 5 over conventional optics. This compression efficiency permitted the team to design a fully enclosed pump chamber that more effectively traps light for exciting the rod. Furthermore, because the CPC's parabolic surface works like a convergent waveguide to direct the light into the pump chamber, no lens is needed to focus the light through the narrow slit. This feature both simplifies laser-head assembly and improves system reliability. The resultant laser head greatly simplifies light delivery to the laser rod and provides a compact and robust package.

The CPC laser head converts more than 40 percent of the diode radiation into infrared laser light, a rate that is 30 to 40 percent higher than that of other commercially available high-power designs. A well-designed high-power optical system then converts 75 to 80 percent of this infrared laser light to pulsed green output via carefully configured nonlinear crystal and acousto-optic Q switches. The rack-mountable, efficient system design enabled the laser to generate a record amount of pulsed green light and to log more than 40,000 unit hours of around-the-clock operations.

Lean and Green for Machining

Over the past few years, the use of pulsed green laser systems has increased. Such systems are proving to be effective tools for high-quality machining because of their small laser spots and good laser–material coupling. Originally developed for the enrichment of nuclear fuels through the Livermore-developed atomic vapor laser isotope separation (AVLIS) process, the DPSSGL looks to be especially useful in precision laser-machining applications. This emerging technology is finding a place in the automotive and aerospace industries for drilling fuel injectors and turbine engines as well as for other precision machining tasks. Such lasers also show promise in certain laser micromachining tasks performed in the electronics industries—for example, to scribe wafers, trim resistors, and drill microscopic holes.

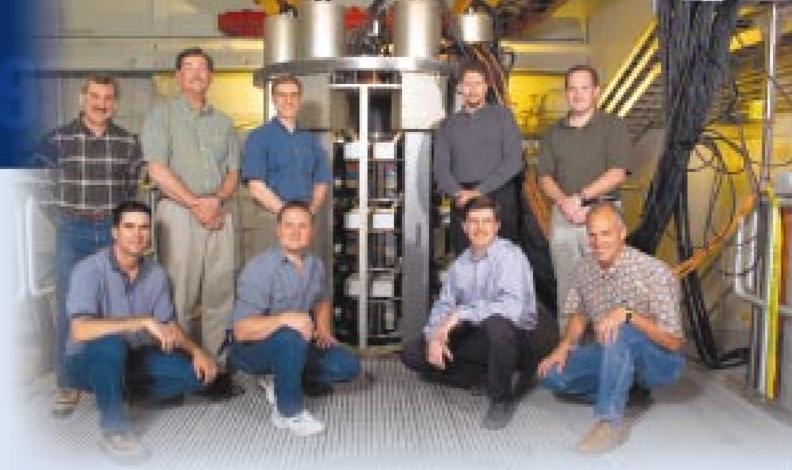
As noted by one of the major suppliers of high-power industrial laser systems, "This type of laser system will lead the push toward the use of diode-pumped lasers in industrial applications that require reliability, power, and good beam quality. There are many industrial applications that may well be opened up by the availability of green power at this level." Another laser company also noted, "The reliable operation record of the Livermore laser has convinced us that high-power diode-pumped lasers have finally emerged as a mature technology." Apparently, the DPSSGL will radically change the business strategy of many industrial laser manufacturers.

—Ann Parker

Key Words: compound parabolic concentrator (CPC), Diode-Pumped Solid-State Green Laser (DPSSGL), industrial lasers, precision laser machining.

For further information contact Jim Chang (925) 422-4064 (chang2@llnl.gov).

Breakthrough Design for Accelerators



The development team poses with their Advanced Radiographic Machine (ARM) modulator. Kneeling, from left to right, are Brad Hickman, Bryan Lee, Craig Brooksby, and Steve Hawkins. Standing are Hugh Kirbie, Craig Ollis, George Caporaso, Roy Hanks, and Rob Saethre.

LIKE many tools of high-energy physics, linear induction accelerators have been improving in small steps over the past several decades. Now a breakthrough design for the accelerator power source has advanced their capabilities immensely. The new design, based for the first time on solid-state components, promises important progress for the Department of Energy's Stockpile Stewardship Program as well as imaginative new uses for accelerators, ranging from waste treatment to space exploration.

The new accelerator power source, called the Advanced Radiographic Machine (ARM) modulator, is the product of a six-year development effort by a team of researchers from Lawrence Livermore and Bechtel Nevada Corporation. The technology enables linear induction accelerators, which typically generate thousand-ampere electron-beam currents at high energies, to fire at up to 2 megahertz (millions of times per second)—a rate some 400 times greater than that of current machines.

A prototype ARM modulator built at Livermore reliably delivers a burst of 45-kilovolt, 4.8-kiloampere pulses that can be varied in length from 200 nanoseconds (billionths of a second) to 2 microseconds (millionths of a second). Its solid-state components permit high recovery rates and are easy to cool, thereby ensuring enormous high-average-power levels.

In addition to performance increases, the solid-state technology provides an unprecedented degree of control over the voltage waveform at each stage of the accelerator, thereby permitting unparalleled flexibility in shaping pulses. The machine also generates pulses in a single-step operation, a feature that differs from conventional technology and contributes to substantial cost savings.

Technology Has a Kicker

The ARM modulator can also power so-called kicker technology, in which an electron beam is divided in half, then half again, to result in four beams, each one-fourth the duration of the original pulse, that are sent down separate pathways. In this way, the ARM technology permits a single accelerator to perform as if it were four—or more—accelerators operating in parallel, thereby achieving dramatic cost savings and contributing to a high level of control and flexibility.

The ARM modulator was developed as part of DOE's Stockpile Stewardship Program to ensure the performance, reliability, and safety of the U.S. nuclear weapons stockpile without the use of nuclear testing. One important part of the program is the use of pulsed radiographs to examine the complex chemical explosive phase of a stockpiled weapon. For these experiments, the weapon's nuclear components are replaced with surrogate materials.

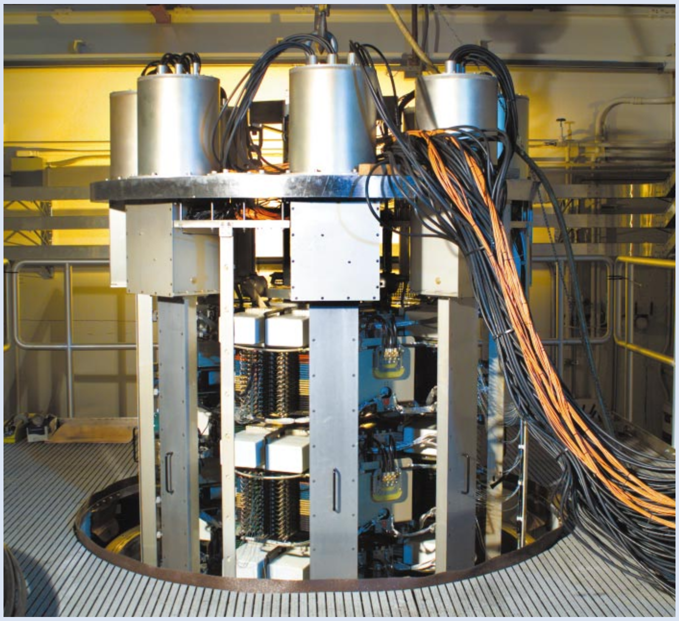
Current DOE linear-induction accelerators, such as Livermore's Flash X-Ray Facility, produce radiographs of exploding warheads from a single, 60-nanosecond pulse of electrons. The beam of electrons typically is focused through a lens down to 1 millimeter in diameter to strike a target, usually tantalum or tungsten, and in the process emits x rays. In each case, the explosive action is imaged for only one moment in time, much like a routine medical x ray.

A single image taken from one vantage point does not provide much data. Weapons scientists need a facility that can produce several consecutive bursts of x rays to image the explosive motion at several moments in time. Ideally, these bursts would examine the explosions from different vantage points to give a three-dimensional assessment of the event, similar to a computed tomography (CT) scan.

Power Modulators at the Heart

Six years ago, a Livermore–Bechtel Nevada team led by Livermore electrical engineer Hugh Kirbie took on the challenge of developing new technology to image imploding warheads over time and from multiple axes. The resulting design is based on power modulators that integrate energy storage, high-speed solid-state electronics, and a hybrid form of transformer, all into one compact package. The modulators can be stacked like flashlight batteries to achieve high voltage and power—to 50-megawatt pulses per modulator and higher.

Even though modern solid-state devices are unmatched in speed, precision, long life, reliability, and cost, their use in the ARM technology is the most radical aspect of its design.



The Advanced Radiographic Machine (ARM) power source, consisting of three stacked solid-state modulators.

Traditionally, it has been difficult to use transistors for high-voltage, pulsed-power systems; they are susceptible to large voltage and current spikes. However, the team overcame those problems with a robust design based on newly available metal-oxide-semiconductor field-effect transistors (MOSFETs).

As testimony to the exhilarating pace of solid-state component development, the original MOSFETs already can be replaced by integrated gate bipolar transistors, which are presently used in bullet trains. The use of these new devices reduces the total parts count drastically and further lowers ARM's overall cost.

The ARM technology will be used to power the kicker system of the Dual-Axis Radiographic Hydrotest Facility (DARHT), now under construction at Los Alamos National Laboratory. The kicker system will create four approximately 50-nanosecond pulses from a 2-microsecond pulse to enable four stop-action radiographs from two axes for every experiment. Although not truly three dimensional, the images will be far more informative than any similar radiograph produced to date. For the first time, researchers will obtain time-resolved information, including shapes, densities, and chemical explosive material distribution within the detonating warhead.

Valuable and Varied Uses

In a related project, team members will investigate using the ARM modulator technology to power an accelerator testbed to study DARHT x-ray targets. When an electron beam strikes a metal target to generate x rays, it blows a hole through the target. Facilities such as DARHT, with their multiple bursts of x rays, will ultimately require a system to provide fresh targets rapidly.

The ARM technology can easily be adapted to a number of other important research and development applications because of the power source's combination of unprecedented high pulse-repetition rates, reliability, and beam control. The team is investigating the technology as a driver for heavy-ion fusion to replace large laser systems now in use. A commercial fusion reactor would require a power source such as ARM that can operate at several hundred kilohertz.

The team is also collaborating with Stanford Linear Accelerator Center scientists to develop an all-solid-state power source for the Next Linear Collider, now under study as the follow-on to current high-energy physics experiments worldwide. Lawrence Livermore is one of the principal partners in planning this international facility that will study exotic new elementary particles.

For a more day-to-day application, the ARM can be used as a high-voltage power source for cleaning exhaust gases in flues. Other applications include large-scale radiation processing of food products, sterilization of medical equipment, transmutation of atomic waste, and strengthening of materials and tools by firing selected ions into their crystalline structures.

An intriguing possibility is using the technology to convert electron-beam power into laser light via free-electron lasers. In this application, the intense light could be used to power a space station, destroy hostile missiles or aircraft, or propel space vehicles.

The team believes that commercial ARM modulator units for myriad applications could be produced at substantially reduced prices through large production runs. In addition, there is every indication that the power-handling capacity of larger solid-state devices will continue to expand while their costs continue their steep decline. Clearly, linear induction accelerators powered by ARM technology face a bright future.

—Arnie Heller

Key Words: Advanced Radiographic Machine (ARM), Bechtel Nevada Corporation, integrated gate bipolar transistors, metal-oxide-semiconductor field-effect transistor (MOSFET), Next Linear Collider, Stanford Linear Accelerator Center.

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New Deposition System for the Microchip Revolution

The team that developed the new precision deposition system. Standing, from left to right, are Jim Folta, Stephen Vernon, Mark A. Schmidt, Gary Heaton, and Richard Levesque. Kneeling are Fred Grabner, Marco Wedowski, Christopher Walton, Claude Montcalm, and George Wells. Not pictured are Gary Howe and Eberhard Spiller.

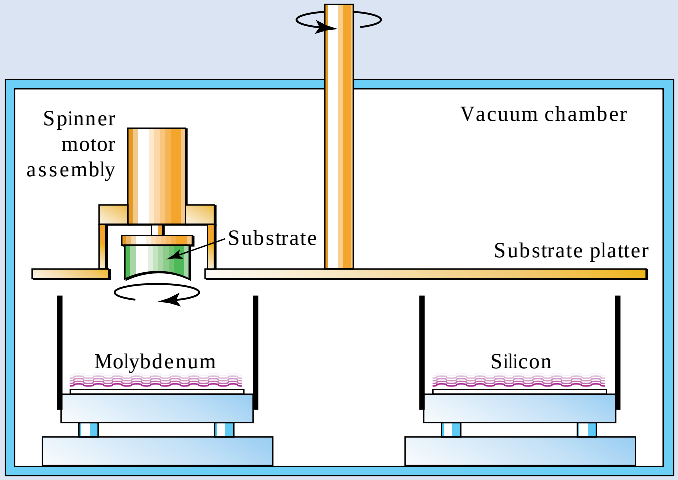
As silicon microchips become smaller and smaller with more and more information printed on them, they will require improved chip printing methods—current methods will not be usable within the next decade or so. Companies around the world are exploring several next-generation methods, with extreme ultraviolet lithography (EUVL) emerging as the leading candidate. A new invention from Lawrence Livermore is taking EUVL one step closer to reality.

Today, microchips are made by projecting binary circuit patterns onto a photoresist-coated silicon wafer. The size of the features on the chip is limited by the shortest wavelength of light that the lenses in the projector will transmit. When the wavelength is as short as about 140 nanometers, light is absorbed rather than transmitted, so lenses no longer work. Instead, mirrors can be used to reflect the light and allow the use of much shorter wavelengths. With wavelengths at the extreme edge of the ultraviolet spectrum (about 13 nanometers), microprocessor features can be made as small as 30 nanometers. In comparison, the smallest features produced by current lithographic methods are 180 nanometers.

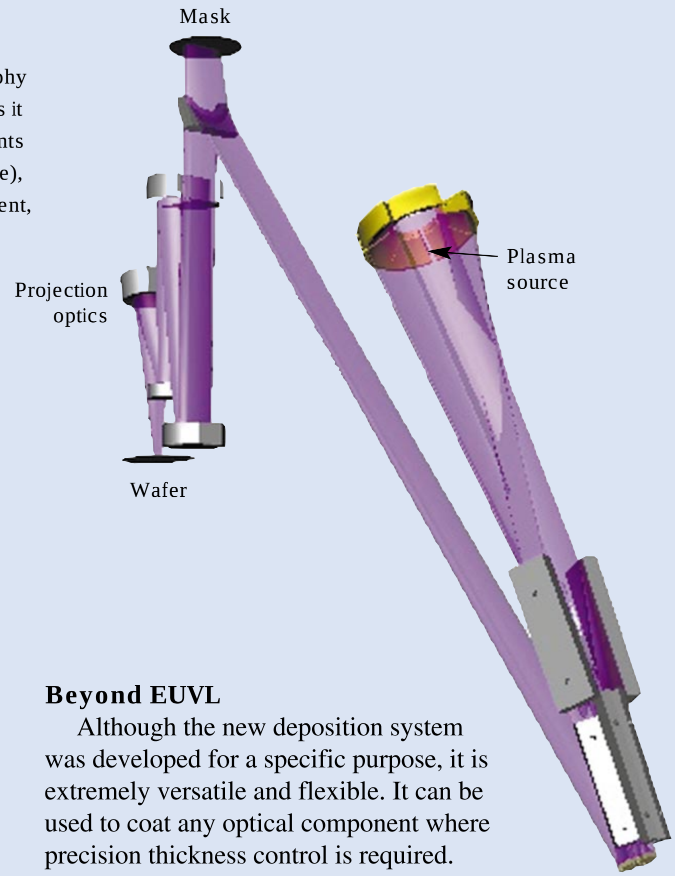
Making a success of EUVL is requiring a number of major engineering and scientific advances. The manufacture of the mirrors has presented a challenge because they must be highly reflective, with surface coatings that are essentially perfectly uniform. Perfect uniformity is difficult enough with a flat mirror, but in EUVL, many mirrors are concave or convex. Nonuniform multilayer coatings destroy the surface figure (shape) of the optics, resulting in distorted lithographic patterns printed on the chips. Until now, the aberrations in the mirrors caused by conventional multilayer deposition systems have been an obstacle to the advancement of EUVL.

But Livermore engineer James Folta and his team have found a way around this problem. They have developed a faster, cheaper, and more precise method for depositing multilayer thin films over large mirrors, whether flat or curved. The system is so precise that 81 alternating layers of molybdenum and silicon, each about 3.5 nanometers thick, can be deposited with the total thickness controlled to within one atom over a 150-millimeter area. The technique can be used to coat mirrors as large as 40 centimeters in diameter.

Emmanuel Lakios, the executive vice president of Veeco Instruments Corporation of Plainview, New York, says enthusiastically, “The Livermore approach to controlling multilayer thicknesses on curved surfaces is truly revolutionary, not only in its ability to achieve atomic-level thickness control, but also in its ease of manufacture.” Veeco is developing a new product based on Livermore’s deposition method.



In the coating system, the substrate platter passes the optical substrate over each sputter source sequentially. The platter velocity is modulated to provide precise control of the radial thickness distribution and absolute film thickness of the coating. The substrate is also spun fast about its own axis for azimuthal (circular) uniformity.



The optical layout for extreme ultraviolet lithography (EUVL) demonstrates the complexity of the optics it requires. The six multilayer-coated optical elements have different sizes, shapes (convex and concave), and prescriptions, each of which requires a different, atomically precise deposition process.

The Extreme Ultraviolet Limited Liability Company, a consortium of Advanced Micro Devices Corporation, Intel Corporation, Micron Corporation, and Motorola Corporation, funds Livermore's work on EUVL. The company also supports EUVL research and development at the Lawrence Berkeley and Sandia national laboratories.

Modulating Velocity

The new Livermore technique produces coatings that can meet the stringent uniformity specification of one part per thousand, a tenfold improvement over conventional vapor deposition processes. Computer software controls the distribution of the coating—whether onto a flat, convex, or concave optic—by modulating the velocity of the optic as it passes through the sputter coating system. (See the figure on p. 12 for a schematic of the system.)

According to Folta, "Being able to precisely modulate the velocity of the optic is the key. With our software, producing uniform or graded coatings on curved mirrors is now as simple as producing the same coating on flat ones and with much more precision than before."

For example, a conventional sputter system running at a constant velocity may produce a coating that is too thin at the edge of the optic. With Livermore's system, the velocity can be reduced as the substrate enters and as it leaves the deposition zones—when only the substrate edges are being coated—to compensate for the nonuniformity. Similarly, the velocity can be adjusted to compensate for curved optics or to achieve graded-thickness coatings with atomic precision.

In its use of computer control, this system also makes a major leap by eliminating the masks used to control thickness distribution. The masks require frequent replacement as uniformity drifts; in contrast, the computer controls readily adjust the velocity "recipe." Software control also allows different coating prescriptions to be achieved on separate optics coated in the same process run. The result is a fast, low-cost, high-performance system. Hardware difficulties have been overcome by software solutions.

Beyond EUVL

Although the new deposition system was developed for a specific purpose, it is extremely versatile and flexible. It can be used to coat any optical component where precision thickness control is required. Examples include lenses used in current-generation lithographic steppers, soft-x-ray space telescopes, optics used on synchrotron beamlines, optical pattern or defect inspection tools, robotic optics for advanced manufacturing methods, and optics for inertial confinement fusion target diagnostics.

The method is broadly applicable to producing coatings from many materials, including metals, semiconductors, and insulators. The flexibility of the approach, stability of the deposition rates, and quality of the thin-film structure combine to make this an extremely effective approach to the production of a large class of coatings.

Optics with multilayer coatings form the backbone of many measuring systems, so the availability of highly accurate, multilayer-coated optics will spawn a new family of measurement tools. But the immediate payoff for this system will be in the advancement of EUVL. Its success will help to ensure U.S. leadership in the next generation of chip manufacturing.

—Katie Walter

Key Words: extreme ultraviolet lithography (EUVL), multilayer coatings, sputter deposition.

For further information contact James Folta (folta1@llnl.gov).

PEREGRINE™ Takes Aim at Cancer Tumors

Members of the PEREGRINE team are (left to right) Brian Guidry, Don Jong, Rosemary Walling, Ed Moses, Tom Daly, Sarita May, Paul Bergstrom, Ralph Patterson, Don Fujino, Ron House, Christine Hartmann Siantar, Jim Rathkopf, Clark Powell, and Dave Knapp. Not pictured are Larry Cox, Lila Chase, Dewey Garrett, Steve Hornstein, Bill Chandler, and Alexis Schach von Wittenau.

A revolutionary new tool for analyzing and planning radiation treatment for cancer patients will be appearing in hospitals within the next few years. Using their storehouse of knowledge and data on nuclear science and radiation transport, Lawrence Livermore scientists have developed PEREGRINE, a hardware and software system that addresses the problem of radiation therapy dosage using fundamental physics principles.

Each year, about 100,000 Americans die from cancerous tumors that doctors thought were curable. Using current methods for analyzing radiation, doctors unknowingly leave areas of the tumors untreated. Livermore researchers hope that PEREGRINE will improve the efficacy of radiation therapy by helping doctors to direct the radiation accurately. According to Ralph Patterson, who is leading the project, “The PEREGRINE dose calculation system is the best tool available for accurately predicting radiation dose to tumors.”

Members of the PEREGRINE team hold one patent related to PEREGRINE and have filed three others. Livermore has recently selected the NOMOS Corporation as a partner to transfer this unique system from the Laboratory into medical clinics. (See also *S&TR*, May 1997, “PEREGRINE: Improving Radiation Treatment for Cancer,” pp. 4–11.)

How It Works

PEREGRINE relies on the Monte Carlo mathematical technique to predict the dose delivered to cancer patients receiving photon beam therapy, the most common form of radiation therapy. During treatment, a patient receives trillions of photons. The Monte Carlo method reconstructs the treatment by selecting a random sample of photon particles and tracking them through a computer model of the radiation delivery device and a model of the tumorous region, based on a computed tomography (CT) scan of the patient. Everything that happens to the photons after they leave the x-ray machine—colliding with an electron in the skin, ionizing a hydrogen atom in the blood, perhaps being absorbed by calcium in the bone—is calculated in the model. The fundamental laws of physics and Livermore’s world-renowned collection of nuclear and radiation data serve as the basis for the model.

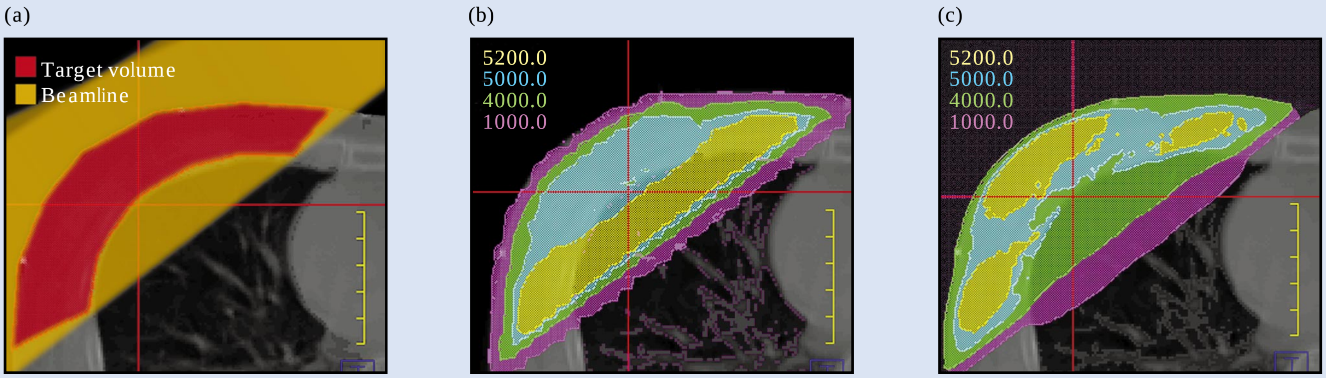
By recording the dose (radiation energy absorbed per unit mass of tissue) deposited by each of the millions of sample particles tracked, the system develops a detailed map of the radiation dose that will be deposited in the patient. This information is graphically displayed, giving doctors the ability to plan treatments that direct maximum radiation dose to the tumor while minimizing damage to nearby healthy tissue.

Scientists have known since the 1950s that the Monte Carlo technique is the best way to accurately calculate radiation dose. The problem has been that these calculations took days or even weeks on computers. As recently as 1995, a full Monte Carlo analysis for a single patient took about 200 hours. But recent advances in parallel computing using small desktop computers allow many processors to operate simultaneously and complete a Monte Carlo radiation analysis in just 10 minutes.

PEREGRINE uses commercial computer boards that support multiple processing and are interconnected with an internal high-speed network. A flexible hardware design allows the system to be configured as needed and upgraded as requirements and computing technology change. The use of hardware commonly found in desktop computers makes the PEREGRINE systems affordable.

Why PEREGRINE Matters

Predictions of radiation dose differ by as much as 30 percent between conventional radiation planning techniques and the Monte Carlo method. Conventional techniques may result in the tumor receiving up to 30 percent more or less radiation than the physician intended. At the same time, healthy tissue may be



This breast cancer case highlights the importance of accurate dose calculations for correct dose coverage of the tumor and sensitive surrounding lung tissue. (a) The radiation applied to the target is shown in general. (b) While conventional dose calculations show that the prescribed dose level covers the entire tumor, (c) PEREGRINE calculations suggest that for this treatment, the prescribed dose shows a higher skin dose, deeper penetration of dose into the lung, and a different dose distribution within the chest wall.

receiving too much. A comparison of conventional and Monte Carlo prediction methods for a case of breast cancer is shown in the figure above.

The Monte Carlo technique is much more effective than conventional methods because it considers the varying densities in the patient's body—of bone, soft tissue, air passages, and so on. This contrasts with current dose calculation methods that model the body as a virtually homogeneous "bucket of water." Even with a CT scan that provides a three-dimensional electron-density map of the body, inhomogeneities such as bone and airways are ignored or highly simplified. Radiation treatments are calculated using interpolated data from dose measurements made in water. The calculations are also based on various simplifications of the way radiation is produced by the source, how radiation travels through the body, and how much energy is deposited.

Some tumors are particularly difficult to treat with radiation because of their proximity to vital organs, the abundance of different tissue types in the area, and the differences in their susceptibility to radiation. Cancers of the head, neck, lungs, and reproductive organs are examples. Too small a dose to the tumor can result in recurrence of the cancer, while too large a dose to healthy tissue can cause complications or even death. Because of the inaccurate dose provided by today's calculations, doctors trying to avoid damage to healthy tissue sometimes undertreat cancerous tissue.

PEREGRINE meets all of these clinical challenges. It can more exactly model the radiation beam delivery system being used for each treatment, accurately model the buildup of dose at the skin surface, and explicitly account for inhomogeneities in the body such as air, muscle, bone, and lung that are identified on the patient's CT scan.

Beyond Photons

About 90 percent of radiation treatment patients receive photon therapy, which is PEREGRINE's principal application. PEREGRINE may also be applied to the less frequently used electron-beam therapy and to brachytherapy, which is radiation therapy from an internally planted radiation source. It is effective for radiography, which predicts the pattern of radiation that is transmitted through a patient or other object. It also promises to advance radiation oncology research into heavy-particle therapy and radioimmunotherapy, which uses the chemistry of the body's immune system to target radioactive compounds at metastasized cancerous tumors.

Widespread use of PEREGRINE dose calculations has the potential to foster more accurate clinical trials and therefore more reliable implementation of clinical trial results. It will also provide accurate estimates of doses required for tumor control and normal tissue tolerance.

Improving the effectiveness of radiation therapy will have immediate, positive results for the hundreds of thousands of people who are diagnosed with cancer every year. With PEREGRINE, the usefulness of radiation therapy may also be broadened, offering a less invasive, less expensive alternative to surgery.

—Katie Walter

Key Words: cancer treatment, Monte Carlo calculations, PEREGRINE, radiation dose, radiation treatment planning.

For further information contact Ralph Patterson (925) 423-6273 (rwp@llnl.gov) or the PEREGRINE Web site http://www-phys.llnl.gov/peregrine/.

Patents and Awards

Each month in this space we report on the patents issued to and/or the awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Patent issued to	Patent title, number, and date of issue	Summary of disclosure
Steven T. Mayer Fung-Ming Kong Richard W. Pekala James L. Kaschmitter	**Organic Aerogel Microspheres** U.S. Patent 5,908,896 June 1, 1999	Organic aerogel microspheres that can be used in capacitors, batteries, thermal insulation, adsorption/filtration media, and chromatographic packing and have diameters ranging from about 1 micrometer to about 3 millimeters. The microspheres can be pyrolyzed to form carbon aerogel microspheres. This method involves stirring the aqueous organic phase in mineral oil at elevated temperature until the dispersed organic phase polymerizes and forms nonsticky gel spheres. The size of the microspheres depends on the collision rate of the liquid droplets and the reaction rate of the monomers from which the aqueous solution is formed. The collision rate is governed by the volume ratio of the aqueous solution to the mineral oil and the shear rate, while the reaction rate is governed by the chemical formulation and the curing temperature.
David J. Erskine	**White Light Velocity Interferometer** U.S. Patent 5,910,839 June 8, 1999	A technique that allows the use of broadband and incoherent illumination. White light velocimetry, a principle that can be applied to any wave phenomenon, is used for the first time with powerful, compact, or inexpensive sources for remote target velocimetry. The sources include flash and arc lamps, light from detonations, pulsed lasers, chirped frequency lasers, and lasers operating simultaneously in several wavelengths. The technique is demonstrated with white light from an incandescent source to measure a target moving at 16 miles per second.
Abraham P. Lee Allen Northrup Dino R. Ciarlo Peter A. Krulevitch William J. Benett	**Microfabricated Therapeutic Actuators** U.S. Patent 5,911,737 June 15, 1999	Microfabricated therapeutic actuators are made with a shape memory polymer (SMP), a polyurethane-based material that undergoes a phase transformation at a specified temperature (Tg). Above Tg, material is soft and can be easily reshaped into another configuration. As the temperature is lowered below Tg, the new shape is fixed and locked in as long as the material stays below Tg. Upon reheating the material to a temperature above Tg, the material will return to its original shape. For example, when fabricated with such SMP material, microtubing can be used as a release actuator for the delivery of embolic coils through catheters into aneurysms. The microtubing can be manufactured in various sizes, and the phase change temperature Tg is the determinate for an intended temperature target and use.
G. Bryan Balazs Zoher Chiba Patricia R. Lewis Norvell Nelson G. Anthony Steward	**Mediated Electrochemical Oxidation of Organic Wastes Using a CO(III) Mediator in a Nitric Acid–Based System** U.S. Patent 5,911,868 June 15, 1999	An electrochemical cell with a cobalt III mediator and nitric acid electrolyte provides efficient destruction of organic and mixed wastes. The organic waste is concentrated in the analyte reservoir where the mediator oxidizes the organics and insoluble transuranic compounds. The analyte is regenerated at the anode until the organics are converted to carbon dioxide. The nitric acid is an excellent oxidant that facilitates the destruction of the organic components. The anode is not readily attacked by the nitric acid solution, so the cell can be used for extended, continuous operation without electrode replacement.
Luiz B. Da Silva Dennis L. Matthews Joseph P. Fitch Matthew J. Everett Billy W. Colston Gary F. Stone	**X-Ray Compass for Determining Device Orientation** U.S. Patent 5,912,945 June 15, 1999	An apparatus and method for determining the orientation of a device with respect to an x-ray source. In one embodiment, the present invention is coupled to a medical device to determine the device's rotational orientation with respect to the x-ray source. In this embodiment, the present invention comprises these parts: a scintillator that is adapted to emit photons when it absorbs x rays emitted from the x-ray source; an x-ray blocking part that is coupled to the scintillator and varies the quantity of x rays that penetrate the scintillator, based on the particular rotational orientation of the medical device with respect to the x-ray source; and a photon transport mechanism, also coupled to the scintillator, that is adapted to pass the photons emitted from the scintillator to the device's electronics, which then analyze the quantity of the photons to determine the rotational orientation of the medical device with respect to the x-ray source.

Awards

Jeffrey Wadsworth, deputy director for Science & Technology, has been named a **fellow** of **The Minerals, Metals, and Materials Society** (TMS), one of the highest honors in the field of metallurgy and materials science. He will be presented with the TMS 2000 Fellow award during the society's awards dinner in March 2000.

Wadsworth is one of only five recipients this year and the only Laboratory scientist to receive the award. For this award, which is limited to 100 current members (out of a worldwide membership of approximately 13,000), Wadsworth was cited for "outstanding contributions in superplasticity, refractory metal alloys and ultrahigh carbon (Damascus) steels, and leadership in promoting materials science in major industry and national programs."

Wadsworth oversees the quality of science and technology in all of Livermore's scientific and technical programs and disciplines. He joined Lawrence Livermore in 1992 as assistant associate director for Chemistry & Material Science and was named associate director in 1994. His B.S. and Ph.D. in metallurgy are from Sheffield University, where he was later awarded an honorary degree, Doctor of Metallurgy, for his published work.

He is a consulting professor in materials science and engineering at Stanford University and an adjunct professor in the Department of Applied Science at the University of California, Davis.

Steven Haan of the Defense and Nuclear Technologies Directorate is one of three winners of the 1999 **Edward Teller Medal**. Presented by the American Nuclear Society, the award recognizes pioneering research and leadership in inertial fusion sciences and applications. The awards were presented September 15 at the First International Conference on Inertial Fusion Sciences and Applications in Bordeaux, France.

Haan is recognized internationally for his work in the design of inertial confinement fusion targets. He is distinguished for work on targets for nuclear- and laser-initiated experiments. His recent work has focused on designing targets for the Department of Energy's National Ignition Facility (NIF) being built at Lawrence Livermore (see S&TR, July/August 1999, pp. 4–11). He is also recognized for developing a first-principles model of weakly nonlinear hydrodynamic instabilities, thereby providing a way to predict the required smoothness of NIF target surfaces.

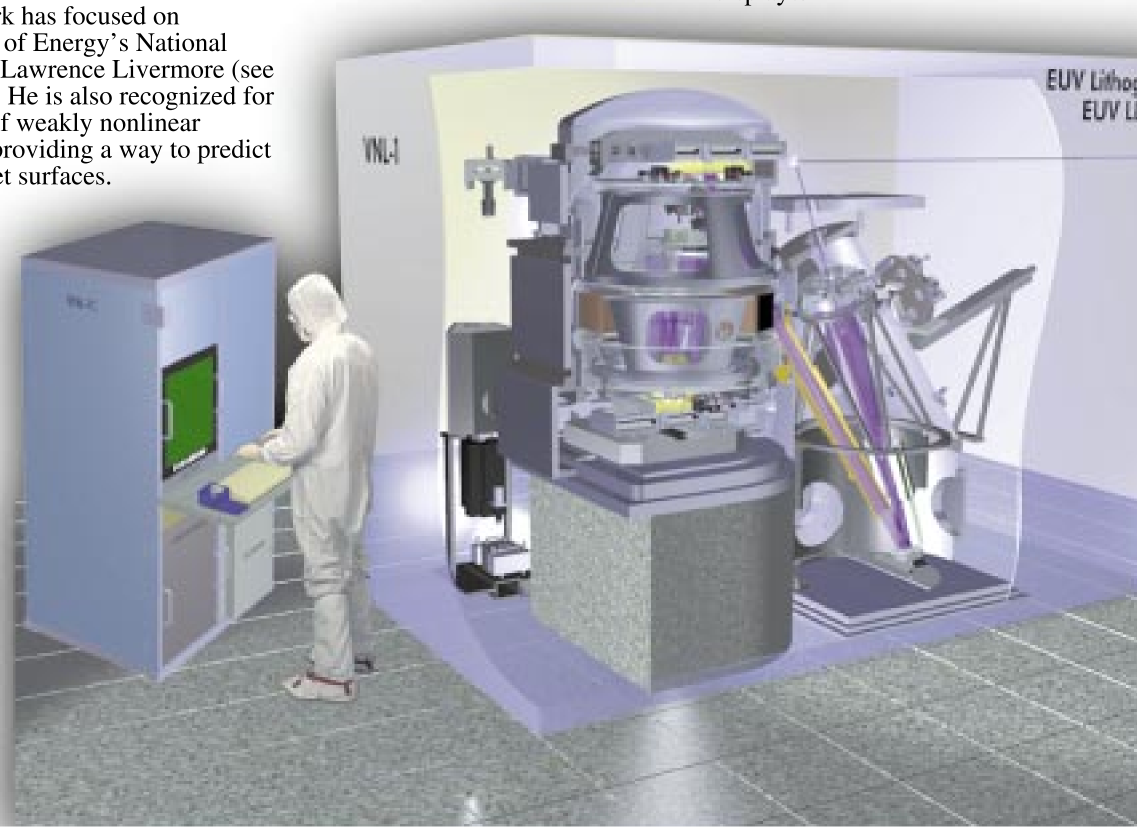
Coming Next Month

Imaging the Future with Extreme Ultraviolet Lithography

A report on how Livermore, in collaboration with Lawrence Berkeley and Sandia national laboratories, is progressing in the race to create the next generation of microchip manufacturing technology.

Also in November

- Advances in portable, hand-held microfluidic sensor systems.
- Developing Mercaptoplex—a new organic polymer to rid the environment of toxic mercury ions.
- Developing the process to replace glass with plastic for flat-panel displays.



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